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Water resources and land use change in the Salinas Valley

A progress report of the hydro-ecological modeling group at
The Watershed Institute, California State University Monterey Bay
Institute for Earth Systems Science and Policy

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Watershed Institute Report No. WI-1999-01

http://faculty.csUMB.edu/PierceLars/world/NASA_SV.html

The Salinas Valley is a socio-economically important watershed of over 11 000 square kilometers. It supports large areas of intensive agriculture, urbanization, vineyards, grazing, national forest, wilderness, and badlands.

It experiences a mainly dry climate with limited surface water resources, and a finite groundwater system.

The balance of land uses is rapidly changing, with effects on water resources.

The hydro-ecological modeling group at CSUMB is attempting to predict these effects, using computer models so that the future impacts of land use change on water resources can be known in advance. This will lead to better-informed planning, and a community that is aware of its economic and environmental limitations.

A valuable watershed

The Salinas River watershed falls roughly half in Monterey County, and half in San Luis Obispo County. It has considerable economic and ecological value.

Monterey County's, Gross agricultural production in 1998 was \$2.3 billion (MCAC, 1998).



Figure 1. Irrigated cropland.

The valley also contains much of the Ventana Wilderness, including rare endemic species such as the

Santa Lucia Fir, thousands of acres of pristine oak woodland, and salmonid spawning habitat.



Figure 2. Five ecosystems: coastal sage scrub, annual grassland, redwood forest, chaparral, and oak woodland.

Current and past land use

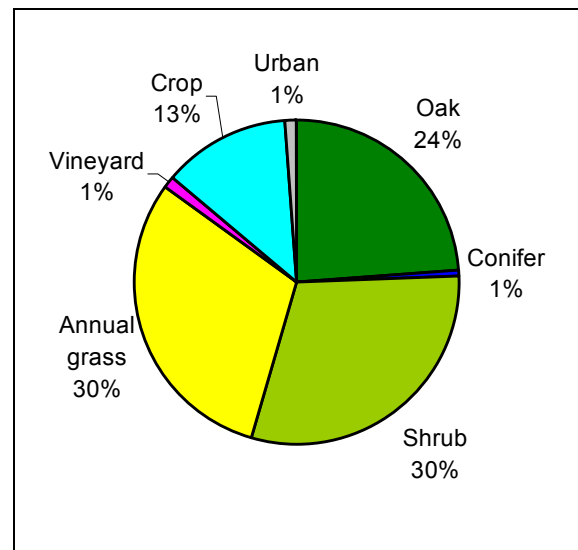


Figure 3. Salinas Valley land use in 1990 (Source: Analysis of California GAP data, Davis et al., 1998)

Currently, a little over half the watershed is comprised of natural ecosystems, including oak woodlands, coniferous forests, and shrub-lands (e.g. chaparral) (Figure 1). Most of the remaining 45% is managed for agricultural production, including large areas of

intensive crop production, and extensive cattle ranches supporting annual grasslands.

Pre-European land cover can be estimated from historical photographs, and the modern landscape of the Hunter Liggett Military Reservation. Much of the valley floor now occupied by crop-lands, appears to have formerly supported oak savannah and wetlands, and the grazed foothills of annual grass formerly supported perennial species.



Figure 4. Valley oak savannah: the ancient valley landscape?

Future land use

Two types of land use change dominate at present, and will most likely shape the landscape of the future. Acreally, the most dominant form of change is the conversion of both grazing lands to irrigated vegetable crops and irrigated vineyards. Between 1984 and 1996, 4650 acres of grazing land were converted to irrigation, with 85% going to vineyards expanding in area at around 1% per year (Source: CA Dept. Forestry & Fire Protection data). In 1998, there were over 40 000 acres of vineyards in Monterey County (MCAC, 1998).



Figure 5. Grapes: the Valley's fastest growing crop.

The other major area of change is conversion of prime agricultural land to urban uses. The population of Monterey county is projected to increase by 37% to

537 000 by 2020, with urban lands increasing by 23 800 acres to over 70 000 acres (LandWatch, 1999).

Threatened water quantity and quality

Most water used in the Valley comes from groundwater. Agriculture accounts 92.5% of extractions, and urban consumption accounts for the remaining 7.5%. Extraction exceeds recharge by about 40 000 to 50 000 acre feet per year (LandWatch, 1999). The water is running out.

Nitrate agricultural fertilizer has contaminated the groundwater. In 1995, 38% of wells exhibited nitrate levels exceeding human consumption standards (MCWRA, 1997).

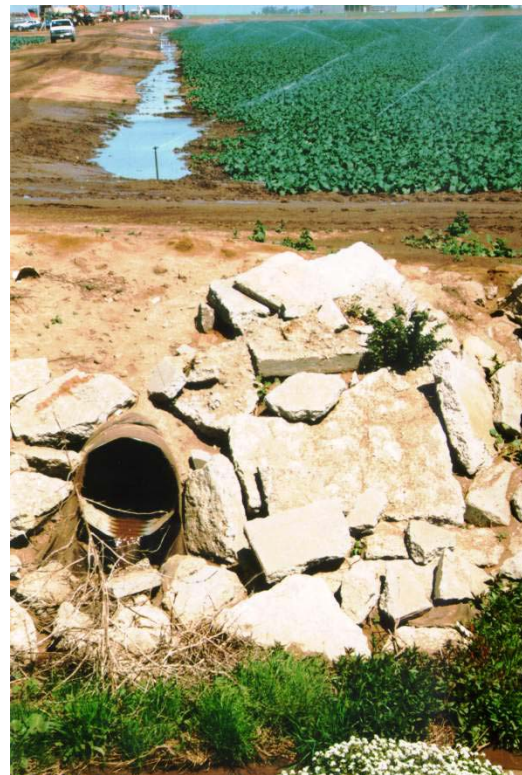


Figure 6. 'Fertigation' tailwater running directly into a stream.

Lowered groundwater levels have allowed sea-water to intrude several miles inland, contaminating both urban and agricultural extractions (MCWRA, 1997).

The threat of control

The Salinas River is listed by the EPA's Total Maximum Daily Load (TMDL) Program as being threatened by pesticides, nutrients, sedimentation, and salinity. Potential sources of these problems are listed as agriculture, land development, and range lands.

(http://www.epa.gov/iwi/303d/18060005_303d.html)

Governmental control of these listed activities with respect to TMDLs may occur soon. This could have a major impact on the way land users operate.

Predicting impacts of land use change

The ability to predict the hydrological and ecological impacts of land use change has clear benefits to the community. Primarily, it facilitates better-informed planning. Detrimental changes can be avoided, and beneficial changes can be promoted.

Indirectly, it also provides a better understanding of how the watershed works. Many components of the Salinas Valley are connected. It is important to understand these connections.

Prediction is made easier through the use of computer models. They enable us to represent complex patterns of the ecosystems of the land and the physical processes occurring within them. They then allow us to ask "What if?" questions by expressing different past and future scenarios.

We describe our progress toward the use of computer modeling to provide both understanding and predictive capability in a number of steps:

Hydro-ecological understanding

The Salinas Valley is dry. Natural plant growth is limited by water availability.

A wide flat valley floor runs north-south, flanked to the east and west by mountain ranges 1000 to 2000 meters high. Most precipitation occurs in these ranges, particularly the west one. Falling almost exclusively during winter, it runs off the generally shallow soils into fast flowing streams. When these streams reach the valley floor, much of the water disappears underground into a series of large, deep groundwater aquifers.

In pre-European times, the water was clean, and lingered long enough for salmonid fish species to swim up to headwater streams to spawn.

The ways in which current land uses have altered this system can be summarised as follows:

- A proportion of winter streamflow is retarded by large storage reservoirs and released during the drier months to recharge groundwater via stream percolation.

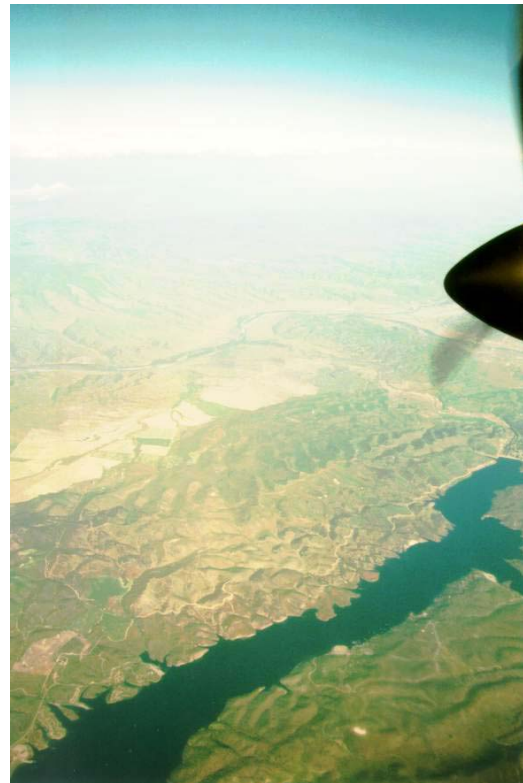


Figure 7. Lake San Antonio: an artificial storage used for summer recharge of downstream groundwater.

- The Valley's vegetable crops rely on irrigation and fertilization. They use more water and discharge more nutrients than their natural counterparts. Irrigation is taken from groundwater, limited only by pumping costs. Groundwater levels are lowering. Near the ocean, the groundwater is being intruded by salt water. Water used by the crops is evaporated at a higher rate than the natural vegetation it replaced, amounting to a net increase in the amount of water lost from the Valley. Water not used by crops may be enriched by unused fertilizer, particularly nitrate. It can drain back down to the groundwater, taking as long as 40 to 60 years (U.C. Davis, 1995). Alternatively, it can run directly into drainage ditches, streams, and the ocean.
- Cattle graze on annual grasses over large foothill ranges. Formerly, winter rains in these areas fell on already-established perennial grasslands, which may have retarded soil erosion more than is currently the case. The timing of water use by annual and perennial grasses also differs. Annuals extract water from the soil over an intense few months following rain. Perennials, spread this pattern over a much longer period. The long term impacts of this difference on water resources are uncertain.



Figure 8. Cattle grazing in the dry south east.

- Large vineyards, and other crops, are being established on areas formerly used for grazing. Owing to their use of irrigation, vineyards use more water than grazing lands. However, the water-use differences between vineyards and vegetable crops are uncertain.
- Urban lands are replacing agricultural lands. Water use per unit area is lower in urban areas than in the irrigated areas of the Salinas Valley. However, urban lands contain many impervious surfaces, and so rainfall runs very quickly to streams, sometimes causing flooding. Urban areas are a source of a variety of pollutants, and urban drainage systems can be very efficient mechanisms for delivery of these pollutants to streams.
- The natural ecosystems of the Valley are subject to fire. Few wild areas have not been burnt in the past 30 or so years. Fires remove some or all of the vegetation. Most sediment from the areas is generated by the winter rains immediately following large fires, such as the Marble Cone fire which burnt nearly 178 000 acres of the Los Padres National Forest in 1977. In 1999, the Tassajara/Hare fires burnt over 85 000 acres of the same National Forest. Through changes in plant water use, fires may also affect the amount of water available for recharge and streamflow.

Data

A diverse array of public data are required for our computer modeling. We have obtained these from many sources:

- Satellite **remote sensing** images of vegetation derived from Landsat-TM, and AVHRR platforms, obtained from NASA EROS data center.
- Regional **climate** data obtained from NCDC.

- Local **climate** data obtained from local agencies (MCWRA, MPWMD).
- **Streamflow** data obtained from USGS.
- Field data on **leaf area index (LAI)**, **leaf water potential**, **plant nutrients**, and **stream chemistry** derived through our own work, and in conjunction with local farmers, and workers at NASA and the University of California.
- Spatial **soils** data from the STATSGO database.

Spatial and temporal patterns

Figure 9 shows an aerial perspective of the land cover of the Valley viewed looking southeast up the valley from above Monterey Bay. In general, agriculture (brown) occupies the flat valley-bottoms, leaving grazing areas (annual grasses; pale yellow) and more wild areas (shrubs, oaks, and conifers; greens) to occupy the steeper terrain of the valley-sides.

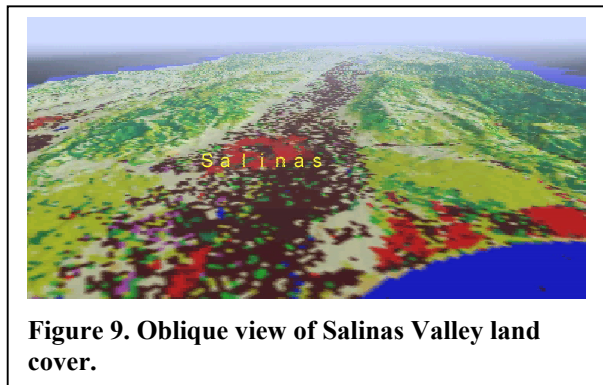


Figure 9. Oblique view of Salinas Valley land cover.

The spatial pattern of water inputs and water outputs to this system is not uniform. Most water enters the system through precipitation in mountain areas. After being transported laterally via surface or groundwater paths, or both, most water leaves the system as evaporation in valley-bottom areas, or as surface flow to the ocean.

Temporal patterns also vary. Almost all precipitation falls in winter. The timing of plant use of this water depends on the ecosystem. Due to the large capacity for groundwater storage, water use in irrigated areas peaks in summer.

Land use change alters the spatio-temporal composition of the Valley. It is important to take these factors into account when modeling this system.

Leaf area patterns & dynamics

A paradigm of hydro-ecological modeling is the use of leaf area index (LAI) as a single value expressing the amount of vegetation present. Because leaves are the primary agricultural products of the valley, and the

pathway through which most of the water in the valley passes, the measurement of leaf area is paramount. We have done this on many levels, from detailed destructive measurements, to remote sensing over large areas spanning many years of data.

The most basic measurements of LAI are made with a planimeter, through which individual leaves are passed (Figure 10). These measurements are used to calibrate estimates made using light meters in the field (Figure 11). We have made thousands of such measurements, resulting in a number of small-area maps of LAI (Fig. 12).



Figure 10. Measuring the area of lettuce leaves with a planimeter.



Figure 11. The AccuPAR sensor: for measuring leaf area index in the field.

Computer models.

We are using a number of models, including Macaque and derivatives of Biome-BGC, as well as a hybrid between the two. Macaque is a large-scale surface-hydrological model, whilst Biome-BGC concentrates more on plant growth and nutrient use. We are also developing simpler models, such as CashCrop, which simulates the economics, water, and plants of a small vegetable farm.

The models concentrate on surface and near-surface processes. They are not groundwater models, such as have been previously used in the Valley.

Biome-BGC runs on a UNIX workstation. Crop-BGC is an augmented port of Biome-BGC running on a desk-top PC. Macaque, MacaqueBGC, and CashCrop run on a laptop PC under the Tarsier framework.

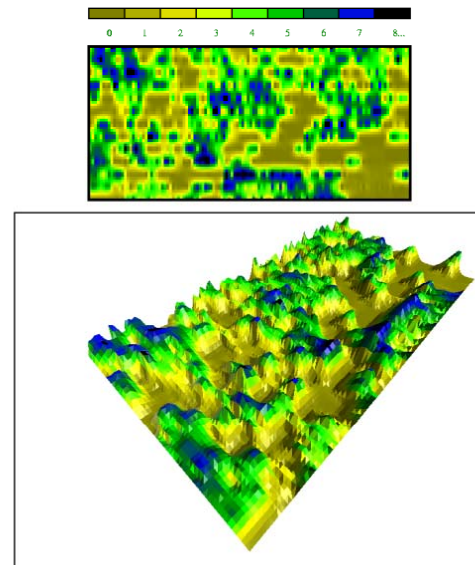


Figure 12. Example small-area LAI map (Mudhen lake area).

Crop-BGC

We have augmented the Biome-BGC model to produce Crop-BGC, which is used to examine the potential of fallow cropping and riparian buffer strips to reduce stream and groundwater nitrate pollution. Crop-BGC simulates irrigated, fertilized crops, which are planted and harvested several times a year. They grow using light, water, and nutrients. They also discharge water and nutrients to neighboring wetlands and riparian buffer strips, where riparian vegetation is grown and used to absorb excess nitrogen.

Macaque

Macaque is primarily a large-scale surface-hydrological model. It was developed in Australian temperate areas where there is year-round precipitation and streamflow. A key step was then to test it in the Salinas Valley, where precipitation and streamflow generally only occur for a few months in winter.

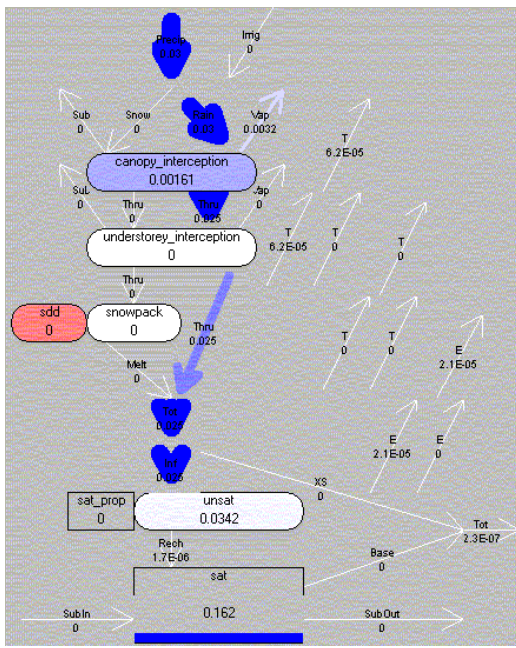


Figure 13. Part of the Macaque user interface, illustrating the hydrological structure of the model.

The model usually operates spatially, by dividing watersheds in hundreds of separate parts, which are simulated separately. However, it can operate in a 'lumped' capacity also. It was applied in this way to the Arroyo Seco watershed, a large tributary of the Salinas River containing mainly chaparral and oak woodland ecosystems. A simple comparison of predicted and observed streamflow is shown in Figure 15.

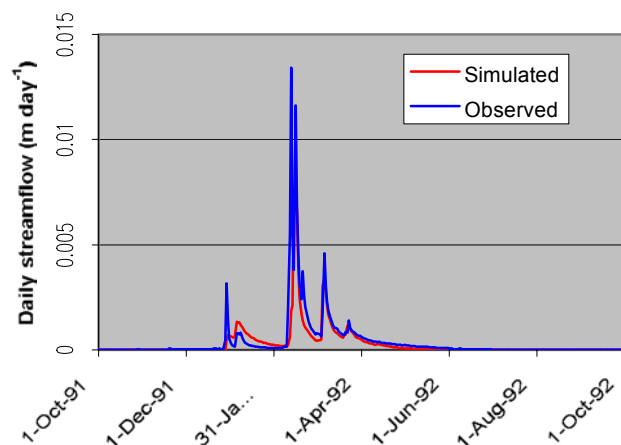


Figure 14. Modelled daily streamflow at Arroyo Seco for the 1992 water year (lumped simulation).

Clearly, non-perennial flow conditions are able to be simulated by the model. However, there remain limitations. Figure 16 shows the same simulation for a longer period on a monthly-averaged basis. Many years show significant discrepancies between simulated and observed streamflow. We attribute these

mainly to limitations in the scheme used to estimate watershed-wide precipitation, but possibly also to other factors such as under-estimated soil water storage, under-estimated plant water use, and the spatially lumped nature of the simulation. Each of these has been investigated further, with results pending. Note that the simulation presented here involved no calibration of any parameters. All parameters were based on measured data.

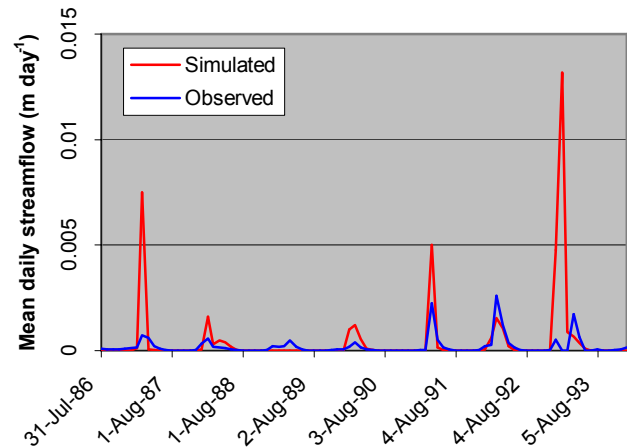


Figure 15. Mean daily streamflow for each month of a seven year, lumped simulation at Arroyo Seco.

The next level of complexity, after simple lumped hydrological simulations, are spatial hillslope-hydrological simulations. Again at Arroyo Seco, we have used such simulations to examine Macaque's ability to simulate flow generation throughout the arid, shallow soil catenas typical of the mountainous parts of the region. Whilst the resulting hydrograph predicts flashier flows than are observed at the weir (Figure 17), simulated spatial patterns of flow generation are consistent with expectations.

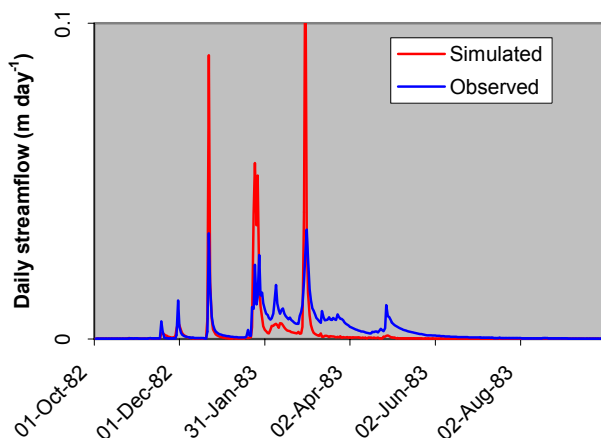


Figure 16. Modelled daily streamflow at Arroyo Seco for the 1992 water year (spatial simulation).

Water use of natural ecosystems

One question that arises from the simple Arroyo Seco simulation presented above is "How much water do the chaparral and oak woodland plants of that area use?" In temperate parts of the world, this question can often be answered from the difference between precipitation and runoff. However, in the Salinas Valley, these values are almost equal. On a watershed-wide basis, their estimation is highly uncertain. This uncertainty is even greater when examining the difference between the two.

One approach is to examine the difference between runoff when the plants are present, and when many of them have been destroyed by fire. An analysis along these also tells us about the effect fires may have on water yield for domestic supply, a key issue in the adjacent Carmel Valley.

Figure 18 shows a simple analysis of the impacts of fire based on a comparison of actual streamflow with streamflow that would be expected based on relationships established between precipitation and streamflow in the period prior to the fire. The figure suggests that there may be some impact, by that there are extraneous influences such as the record water year of 1983. A more detailed statistical analysis is underway. Clearly, the impact is small, perhaps 100 to 200 mm year^{-1} at most. But this figure needs to be related to the proportion of the Los Padres watershed that was actually burnt by the fire.

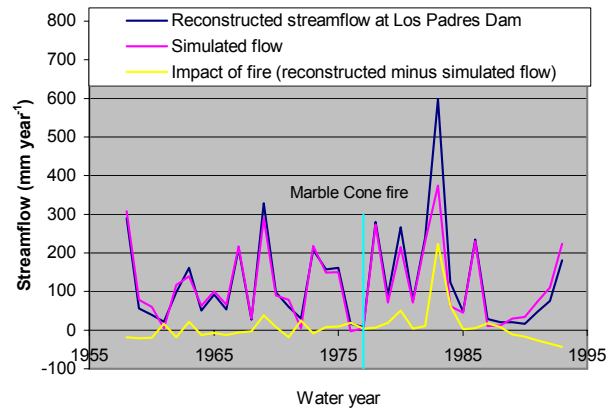


Figure 17. Simple analysis of the impact of the 1977 Marble Cone fire on streamflow at Los Padres Dam.

Predictions of the effects of land cover change

The hybrid model, MacaqueBGC, is a large-scale hydro-ecological model. It represents complex spatio-temporal patterns of land cover. Using simple climatic inputs, it estimates the micro-climate experienced by all parts of the landscape. The growth of plants is then simulated, including their use of water and nutrients. Conjointively, the vertical and lateral movement of water and nutrients is modelled.

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